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(54) Representation of video im-
ages transmitted at reduced
frame rate

(57) A method and apparatus for the
representation of video images, in
particular aerial images with a rela-
tive movement between a pick-up
sensor and the scene, transmitted
at reduced frame rate. Intermediate
frames (n) are interpolated or extra-
polated, to be inserted between two

transmitted frames (O;N), by corre-
lating the locations of a small num-
ber of distinct corresponding refer-
ence points ($A_0, B_0, C_0; A_N, B_N, C_N$)
in the two transmitted frames (O;
N), said reference points being situ-
ated in different vertical and hori-
zontal coordinates within each of
said two transmitted frames (O; N),
calculating for each picture element
in said intermediate frames (n) the
locations of the corresponding pic-
ture elements in each of said two
transmitted frames and determining
the value of the intensity for each
picture element (C_n) of said inter-
mediate frame by interpolation and/
or extrapolation. One of said two
transmitted frames can be repre-
sented as a still picture for a certain
period of time followed or preceded
by a series of reconstructed inter-
mediate frames providing a moving
picture.

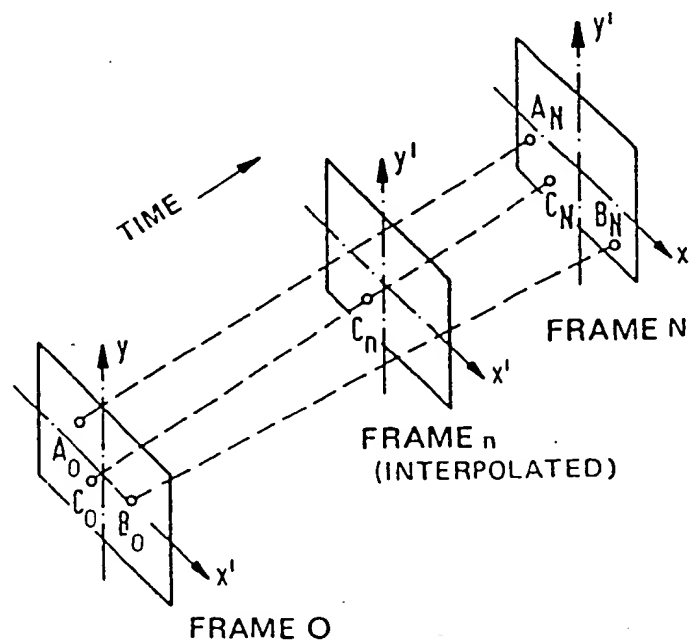


FIG.3

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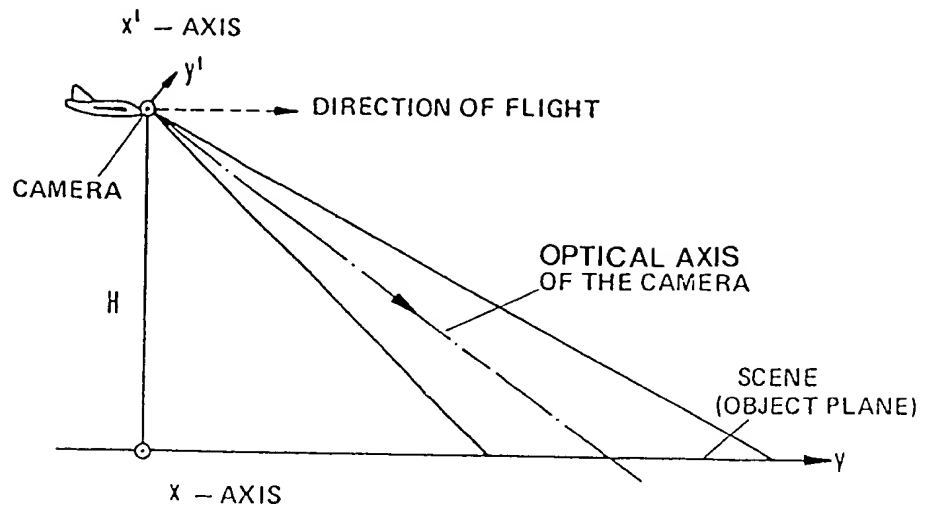


FIG. 1

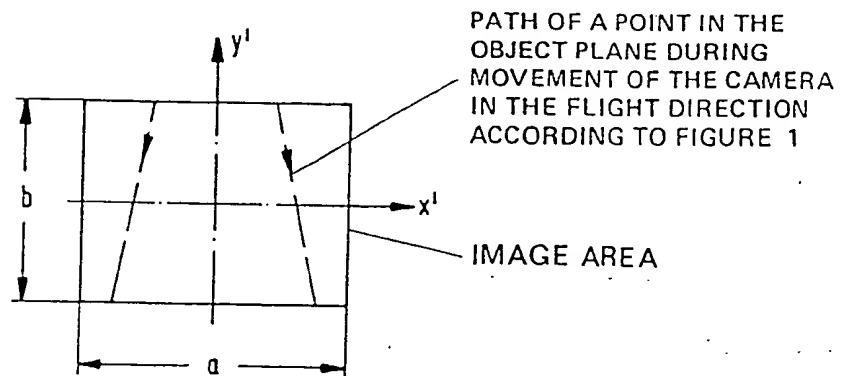


FIG. 2

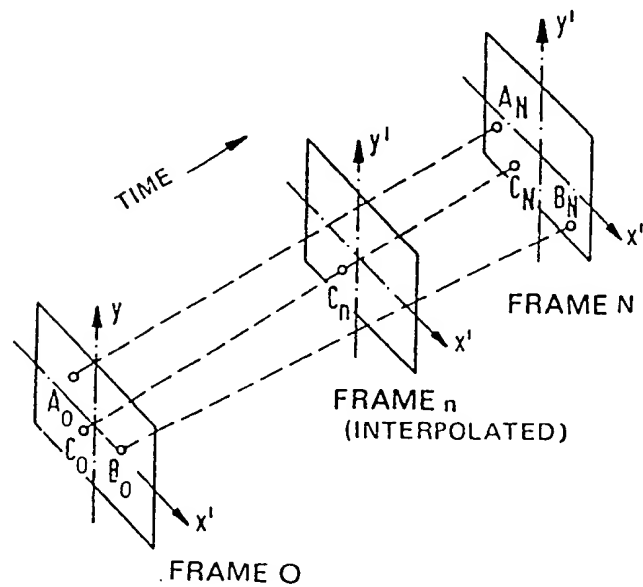


FIG. 3

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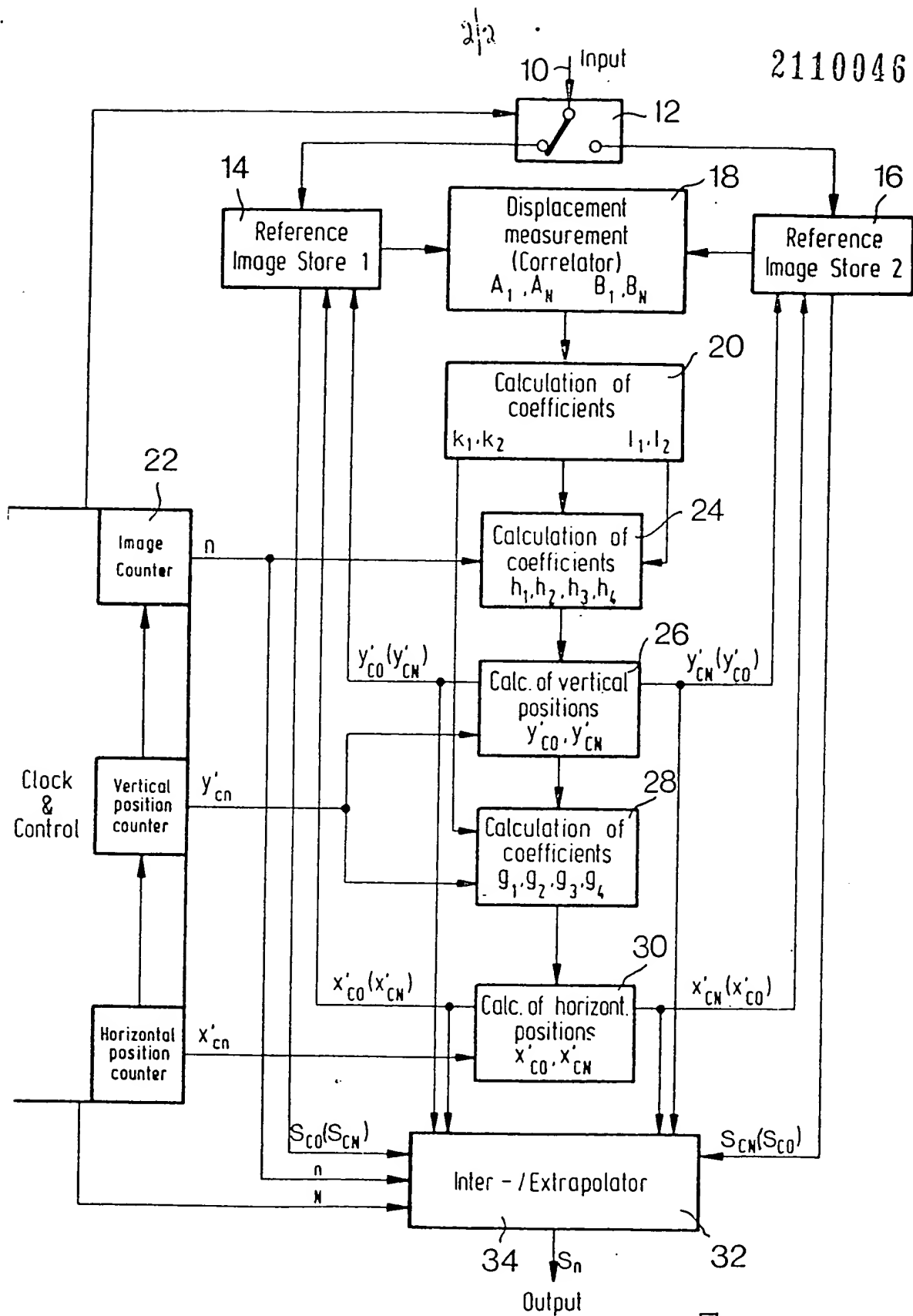


Fig. 4

SPECIFICATION

Method for the representation of video images or scenes, in particular aerial images transmitted at reduced frame rate

The invention relates to a method for the representation of video images or scenes, in particular aerial images with a relative movement between a pick-up sensor and the scene transmitted at reduced frame rate.

BACKGROUND OF THE INVENTION

The task of improving and designing efficient and reliable RF systems for the noise-resistant transmission of moving video aerial scenes, especially from remotely piloted vehicles (RPVs) to ground stations, motivates an increasing interest in suitable techniques for reducing the bit rate in the digital TV baseband. Major candidate techniques, as reviewed by Camana (1979, IEEE Spectrum 16, 24-29) are based on transform or DPCM image coding, operating at the range of approximately 1 to 2 bits per picture element (pel), transmitted either at the standard or a lower TV frame rate.

As aerial scenes transmitted at standard frame rate, e.g. 25 frame/s, often show a largely overlapping image content of subsequent frames, the use of a lower frame rate is capable of providing low-complex, efficient transmissions with a relatively high degree of bit rate reduction, such as by a factor of 25 or more. However, to the human eye, the frame-to-frame discontinuity of the displayed scene movement (jerkiness), usually present in frame-repeated images, is annoying. On the other hand, the scene movement during the interval between successive transmitted frames is largely determined, so that a priori knowledge exists which can be utilized for a regeneration of the continuous scene movement in the received image sequence.

DESCRIPTION OF THE PRIOR ART

A method described by Hershberger and Vanderkolk (M.L. Hershberger, R.J. Vanderkolk "Video Image Bandwidth Reduction / Compression studies for Remotely Piloted Vehicles", Final Tech. Rep. January 1975—May 1976, ASD-Tr76-26, AD-A039762, Hughes Aircraft Co., Culver City, Calif. 90230, October 1976), for example, shifts the image displayed during the time interval between one transmitted frame and the next, uniformly in accordance to the sensor movement, based on received flight data. The image is updated by the next transmitted frame.

Object movements within the background of the image are not appearing in this case. In addition, there is a disadvantage that due to the image shift, regions uncovered by the image occur to an increasing degree and

these gradually limit the field of vision and are, in each case, only refilled when the image of the next transmitted frame is read-in and appears on the display. The information required on the reception side for calculation of the image shift is obtained from transmitted data of measurements on the aircraft and parameters of the system for picking-up the image.

It is an object of the invention to provide a method and apparatus which with the transmission of images, in particular aerial images or scenes, at reduced frame rates makes it possible to represent a continuous scene movement, whereby the image displayed is filling the field of vision of a display substantially completely also during the time interval between two successive transmitted frames.

SUMMARY OF THE INVENTION

In accordance with the present invention intermediate frames are constructed to be inserted between two transmitted frames, said reproduction starting from a small number of distinct corresponding reference points in the two transmitted frames, said reference points being situated in different vertical and horizontal coordinates within each of said two transmitted frames, and being determined by correlation of image point locations within said transmitted frames calculating for each picture element in said intermediate frames the locations of the corresponding picture elements in each of said two transmitted frames and determining the value of the intensity for each picture element of said intermediate frame by interpolation and/or extrapolation and issuing said value and including the step of representing one of said two transmitted frames as a still picture over a certain period of time followed or preceded by a series of reconstructed intermediate frames providing a moving picture.

DESCRIPTION OF THE DRAWING

The present invention will be more readily appreciated by reference to the following detailed description when read in light of the accompanying drawing in which:

Figure 1 shows the general geometric system for obtaining aerial TV image sequences from a height H above the ground with the TV camera directed obliquely forward (the x- and x'-axes are perpendicular to the plane of the drawing);

Figure 2 shows the x-y plane of the aerial scene (scanned ground area) projected into the x'-y' plane of the image area viewed in the flight direction according to Fig. 1,

Figure 3 shows the principle of the reconstruction of intermediate frames,

Figure 4 is a block diagram of an apparatus for carrying out the method in accordance with the present invention.

DETAILED DESCRIPTION

In the general geometric system according to Fig. 1, aerial image sequences are obtained by a preferably stabilized image sensor (camera) with an oblique depression angle moving over the x y object plane parallel to the y axis. Thereby the x y plane of the aerial scene (scanned ground area) is projected into the x' y' plane of the image area as shown in Fig. 2. Straight lines which extend parallel to the y-axis in the scene being photographed are reproduced in the plane of the image (Fig. 2) as straight lines inclined to the y-axis according to the perspective of the reproduction. At the same time they represent, in each case, the geometric location of a picture element (pel), (here the path along which the pel moves in the image) during movement of the camera in the direction of flight (see Fig. 1).

The dependence of the positions of a pel of the time, that is its shift from frame to frame is determined by the displacement geometry within the frame sequence. It can be approximated in a simplified manner, as in Fig. 3, by straight lines. If the positions of two pels (reference points) are known in two successive frames 0 and N actually transmitted, for example the pels A_0 , B_0 in frame 0 and A_N , B_N in frame N according to Fig. 3, it is possible to calculate the positions for pels the rest of the image field, for example for the image points C_0 , C_N , from the relationship of the distances between the image points by means of the Ray Ratio Law.

The relationship between the object-equivalent image pels C_0 and C_N and their coordinates x'_{C_0} , y'_{C_0} or x'_{C_N} , y'_{C_N} in the frames 0 and N respectively and the corresponding pel C_n with the coordinates x'_{C_n} , y'_{C_n} in a frame n to be regenerated are characterised by means of a straight connecting line, specific for this pel between the frames 0 and N.

The relationship between the y' and x' coordinates of the corresponding locations C_n , C_0 and C_N , C_N in Fig. 3 can be expressed by the linear equations

$$y'_{C_n} = h_1 y'_{C_0} + h_2, \quad (1)$$

$$x'_{C_n} = g_1 x'_{C_0} + g_2 \quad (2)$$

and

$$y'_{C_n} = h_3 y'_{C_N} + h_4, \quad (3)$$

$$x'_{C_n} = g_3 x'_{C_N} + g_4 \quad (4)$$

the coefficient h_1 to h_4 and g_1 to g_4 can be calculated from the known pel locations A_0 , A_N and B_0 , B_N where h_i ($i = 1, 2, 3, 4$) is constant for each given n (that is within each frame) and g_i ($i = 1, 2, 3, 4$) is constant for each given value of y'_{C_n} (that is within each frame line) (see hereinafter). The chosen form

of the algorithms represented by the equations (1) to (4) is oriented to processing in real time, taking into account a line- and frame-sequential scan format and is thus particularly suitable to the technical realisation of the method.

The algorithms are obtained on the basis of the elementary geometrical relations of the Ray Ratio Law.

Once the locations C_0 and C_N with the sample values (intensities) S_{C_0} and S_{C_N} in the reference frames 0 and N, respectively, have been determined, the value S_{C_n} at the present location C_n in the frame n can be regenerated by the interpolation

$$S_{C_n} = \frac{1}{N} [(N - n)S_{C_0} + nS_{C_N}] \quad (5)$$

where $0 \leq n \leq N$, or, using the sample values from only one frame, by the extrapolation

$$S_{C_n} = S_{C_0} \quad (6a)$$

or

$$S_{C_n} = S_{C_N} \quad (6b)$$

Equation (5) indicates that, in the interpolated image sequence, i.e. as n increases, due to the progressively decreasing and increasing weighting factor of S_{C_0} and S_{C_N} , respectively, the intensities of the frame 0 fade out whereas those of the frame N fade in. This becomes obvious when interpolating between non-movement-compensated scene content, such as objects moving against the scene background, or channel error effects, as described below.

The extrapolation is of interest, for example, in picture parts with non-overlapping scene content between one transmitted frame and the next. Then the coordinate values found from the equations (1) to (4) would exceed the limit of the active image area

$$-\frac{b}{2} \geq y'_{C_n}, y'_{C_n} \leq \frac{b}{2}, \quad (7)$$

$$-\frac{a}{2} \geq x'_{C_n}, x'_{C_n} \leq \frac{a}{2} \quad (8)$$

as it occurs, for example, at the top and the bottom of a vertically moving scene.

In other cases an extrapolation may be convenient instead of the interpolation, for example when the correlation between the reference frames can temporarily be determined only inaccurately.

Object movements within the scene do not appear in a frame (or partial frame) sequence regenerated by extrapolation, while in interpo-

lation, in general these are characterised by a gradual decrease in the intensity. This case, where the interpolation is not based on object-equivalent pels, corresponds in its effect to a fading of the positions of the moving object in consecutive frames transmitted.

The relationships are similar in channel errors. Changes in the sample value of a reference frame caused by channel error increase gradually in the interpolated frame sequence, that is within N frames, and subsequently fade in a corresponding manner.

The corresponding locations of two reference points A_0, A_N and B_0, B_N (representing two object-equivalent image points) in each of the two successive transmitted frames 0 and N—the minimum number of reference points necessary for carrying out the method—can be determined by means of an image correlation method or from measured data of the aircraft known on the receiving side. In order to increase the reliability of decision it is possible to determine the corresponding locations for other pels with subsequent selection according to predetermined criteria (for example, criteria of reliability or majority). If the corresponding locations of the reference points correlation are determined especially for the region of an object moving within the scene, then it is also possible to determine object equivalent pels for interpolation within such regions and the course of movement can thus be reproduced directly instead of by means of an increase or decrease in the intensity as described hereinbefore.

The coefficients h_i and g_i ($i = 1, 2, 3, 4$) used in equations (1) to (4) are defined as follows. The chosen distribution of the equations offers advantages for the course of the calculation operations in a hardware.

$$h_1 = \frac{N}{N - n \cdot 1_1} \quad (9a)$$

$$h_2 = \frac{-n \cdot 1_2}{N - n \cdot 1_1} \quad (9b)$$

$$h_3 = \frac{N(1 - 1_1)}{N - n \cdot 1_1} \quad (9c)$$

$$h_4 = \frac{(N - n)1_2}{N - n \cdot 1_1} \quad (9d)$$

$$g_1 = \frac{1 - k_1 y'_{c_0}}{1 - k_1 y'_{c_n}} \quad (10a)$$

$$g_2 = \frac{k_2(y'_{c_0} - y'_{c_n})}{1 - k_1 y'_{c_n}} \quad (10b)$$

$$g_3 = \frac{1 - k_1 y'_{c_n}}{1 - k_1 y'_{c_n}} \quad (10c)$$

$$g_4 = \frac{k_2(y'_{c_n} - y'_{c_0})}{1 - k_1 y'_{c_n}} \quad (10d)$$

The denominator is equal in each of the 80 equations for the g_i and h_i coefficients, and the substitutions in these equations are:

$$1_1 = 1 - \frac{y'_{A_n} - y'_{B_n}}{y'_{A_0} - y'_{B_0}} \quad (11a)$$

$$1_2 = y'_{B_n} - y'_{B_0}(1 - 1_1) \quad (11b)$$

and

$$k_1 = \frac{d_A - d_B}{d_A y'_{A_n} - d_B y'_{B_n} + x'_{B_n} - x'_{A_n}} \quad (12a)$$

$$k_2 = d_A(1 - k_1 y'_{A_n}) + k_1 x'_{A_n} \quad (12b)$$

where

$$d_A = \frac{x'_{A_n} - x'_{A_0}}{y'_{A_n} - y'_{A_0}} \quad (12c)$$

$$d_B = \frac{x'_{B_n} - x'_{B_0}}{y'_{B_n} - y'_{B_0}} \quad (12d)$$

The coordinates appearing in these equations are the known coordinates of the reference points $A_0(x'_{A_0}, y'_{A_0})$ and $A_N(x'_{A_n}, y'_{A_n})$ or $B_0(x'_{B_0}, y'_{B_0})$ and $B_N(x'_{B_n}, y'_{B_n})$.

With respect to real time processing, the form of the equations (11a)–(12d) is such that they require a numerical evaluation once per reference frame interval, the equations (9a)–(9d) once per frame interval, and the equations (10a)–(10d) once per line interval.

The values of h_i are to be determined once per vertical period (duration of one frame) and the values of g_i once per horizontal period (duration of a line) of the video signal. Via the equations (1) or (3)—in combination with equations (10a)–(10d)— g_i is depending on h_i . The values of $1_1, 1_2, k_1, k_2, d_A$ and d_B must be determined once per N vertical periods.

An embodiment of the present invention which implements the calculations of the equations referred to above is shown in a block diagram in Fig. 4.

Signal samples of a picture frame (image), each of which samples representing the inten-

sity of a pel are applied on input line 10. Via a switching device 12 the samples of successive picture frames are alternatively stored in one of two reference frame or image stores 14, 16. The switching device is actuated each time the samples of a full frame have been stored in one of the stores.

It be assumed that the samples of the earlier frame 0 are stored in store 14. After actuating the switching device the next frame transmitted will be read in into store 16.

By means of a correlator 18 for two pels out of frame 0, namely A_0 with the coordinates x'_{A0} and y'_{A0} and B_0 with the coordinates x'_{B0} and y'_{B0} the related pels A_n with coordinates x'_{An} and y'_{An} and B_n with coordinates x'_{Bn} and y'_{Bn} are detected. From these coordinates coefficients k_1 , k_2 and 1_1 , 1_2 are calculated according to equations (11a, 11b) and (12a-12d) by calculating means 20.

The position of each pel is determined by their coordinates n , y'_{cn} and x'_{cn} in respect of time and its vertical and horizontal position. The actual values of these coordinates are provided by a clock and control unit 22.

For each intermediate frame n ($n = 1, 2, \dots, N-1$) to be interpolated, the coefficients h_1 , h_2 , h_3 , h_4 are calculated by calculating means 24 in accordance with equations (9a-9d). Based on these coefficients h_1 , h_2 , h_3 , h_4 for each vertical position (line) y'_{cn} in an intermediate frame n the related positions y'_{c0} in frame 0 and y'_{cN} in frame N are calculated by calculating means 26 in accordance with equations (1) and (3).

Based on the result of this calculation by further calculating means 28 the coefficients g_1 , g_2 , g_3 , g_4 are calculated in accordance with equation (10a-10d). Based on the result of this calculation for each pel C_n with a horizontal coordinate x'_{cn} the corresponding coordinate x'_{c0} in frame 0 is calculated by further calculating means 30 in accordance with equation (2) and the corresponding coordinate x'_{cN} in frame N in accordance with equation (4).

The values S_{c0} and S_{cN} of the intensity of the pels C_0 (x'_{c0}) and C_N (x'_{cN} , y'_{cN}) respectively determined in this way are read out of the two stores 14 and 16 respectively and supplied to the interpolator-/extrapolator means 32. By these means 32 will be tested whether the calculated values of the coordinates are within the limits given by the equations (7) and (8) and decide thereafter whether the pel C_n to be issued can be or is to be interpolated in accordance with equation (5) or is to be extrapolated in accordance with equations ((6a-6b). In the case of interpolation the weighting coefficients n/N and $(N-n)/N$ are to be calculated. The values of the intensity S_n for each pel C_n thus determined will then be supplied to output line 34 and a displaying and/or recording means.

In the way described all intermediate frames

$n = 1, 2, \dots, N$ are reconstructed. The last frame $n = N$ is identical with the frame stored in store 16. When this frame N is read out of the store 16 the next frame actually

transmitted is to be read in into the store 14. With the frame in store 16 now being frame 0 the cycle described above is repeated.

The calculations are carried out by the different calculating means in a manner known to those skilled in the art.

The method described is, in principle, also applicable when the relationship of pels is described within the temporal sequence by means of the exact equations of the frame geometry instead of by the simpler linear model.

In addition to the interpolation or extrapolation of the frame-to-frame displacement for the whole scene described, a corresponding interpolation or extrapolation may take place for predetermined areas of the frames, for example for objects moving in front of the background, for which it is then necessary to determine the suitable reference points independently or, in general, in order to increase the exactness of the reproduction and/or contrast of individual parts of the image.

The method can, fundamentally, also be used for other purposes with relative movement between a pick-up sensor and a scene.

Depending on the number of intermediate frames, the projection may occur at the original velocity, with quick motion effect, or with slow motion effect.

The quality of reproduction of the intermediate frames inserted into the sequence of transmitted frames by the method described above is in particular depending on the accuracy of the discrete frame representations, the accuracy of the mathematical picture model used for the reconstruction of the intermediate frames and the accuracy of calculations. Depending on the expenditure for realisation there are quality restrictions appearing in a smoothing of steep grey value transitions (reduction of the detail contrast) and edge blurring, which may affect the recognizability and thus the possibility to evaluate picture details.

Evaluation of picture detail may be improved without substantially increasing the expenditure by each time displaying the first of two transmitted frames as a still picture presentation for a given period of time, said presentation being followed by a series of intermediate frames being reproduced in accordance with the method described above.

The term "still picture" means the reproduction of a frame without changing frame elements. The presentation of the still picture is typically effected by repeating the reproduction of the stored transmitted frame 0 with the frame rate of the chosen video standard.

During the still picture presentation for a given period the frame is not subjected to the restriction mentioned above. Thus the opera-

tor can concentrate on details of the picture (e.g. details of a target) during the still picture representation. The following presentation of moving pictures has the purpose to transfer the operator with little symptoms of fatigue to the next transmitted frame represented again as a still picture. It enables him also to realize possible movements of objects on the background of the image. The operator can readily track areas of interest, especially if there is large displacement between successive transmitted frames. In general this avoids loss of time for searching in the next picture for the corresponding area of interest. By the possibility to obtain detailed information during the still picture period or phase given restrictions in reproduction quality during the moving picture period are less important than in case of continuous presentation of moving pictures.

When using this kind of representation in real time, the moving picture period is presented in quick motion, since the time available for presentation of the frames is shorter than the normal number of reconstructed intermediate frames, in this case shorter than the time interval between two transmitted frames. For example, if the moving picture period may be 1 second out of 4 seconds chosen as interval between two successive transmitted frames (corresponding to a rate of 0.25 transmitted frames per second), then the duration of still picture period is 3 seconds.

In case of extremely quick motion representation during the moving picture period, it may be advisable to display the scene movement starting with slowly increasing speed and terminating with slowly decreasing speed instead of displaying with constant speed. A slowly increasing and decreasing of the speed of the scene movement is subjectively more advantageous for the observing operator compared with an instant start and stop of the scene movement. The speed can be made variable according to a triangular, trigonometric (e.g. sine; cosine) or exponential or a polynomial time function.

Also the duration of the still picture period can be variable. It is possible to realize the implementation in such a way that the operator can optionally select still picture presentation, e.g. if it is desired to recognize details more clearly. It is possible to select a still picture period either manually or automatically. An automatic selection may be done e.g. depending on predetermined frame elements. If successive transmitted frames are sufficiently overlapping, it is possible to extend the still picture period over the duration of a normal transmission period by ignoring one or more transmitted frames, i.e. operating with a greater frame-to-frame interval, e.g. by suppressing every second frame.

The ratio of the duration of the still picture period and the duration of the moving picture

period can be chosen differently for individual frame areas. In particular the still picture presentation may be restricted to an area of the frame, e.g. an area in the center of the picture, while the rest of the picture is represented moving.

Optionally it is possible to increase or decrease the time of presentation for a whole scene presentation compared with the operation in real time. In particular it is possible to extend the time for the scene presentation proportional to the duration of the still picture period, in order to display the moving picture period at the speed of the real time operation, i.e. without quick motion.

CLAIMS

1. A method for the representation of video image sequences or scenes with a relative movement between a pick-up sensor and the scene transmitted at reduced frame rate, wherein the improvement consists in the reproduction of intermediate frames to be inserted between two transmitted frames, said reproduction starting from a small number of distinct corresponding reference points in the two transmitted frames, said reference points being situated in different vertical and horizontal coordinates within each of said two transmitted frames, and being determined by correlation of image point locations within said transmitted frames, calculating for each picture element in said intermediate frames the locations of the corresponding picture elements in each of said two transmitted frames, and determining the value of the intensity for each picture element of said intermediate frame by interpolation and/or extrapolation and issuing said value, and including the step of representing one of said two transmitted frames as a still picture over a certain period of time followed or preceded by a series of reconstructed intermediate frames providing a moving picture.

2. A method according to Claim 1 in which the interpolation is based on a model of a linear relationship in the corresponding locations of the picture elements within all reconstructed intermediate frames.

3. A method according to Claim 1 including the step of: representing the reconstructed intermediate frames at the beginning with slowly increasing speed of movement and towards the end with decreasing speed of movement.

4. A method according to Claim 1, in which the length of said still picture period is variable.

5. A method according to Claim 1 in which only a partial area or partial areas of the intermediate frames is presented as a still picture.

6. An apparatus for the reproduction of video scenes transmitted at reduced frame rates comprising storage means for alterna-

- tively storing the transmitted frames, correlation means for detecting a small number of at least two distinctive corresponding reference points in said stored frames, means for calculating auxilliary coefficients from the coordinates of said reference points, means calculating the vertical and horizontal positions in the stored frames for each picture element in the intermediate frames to be reconstructed, and
- 10 means for interpolation and/or extrapolation of the intensity of each picture element of said intermediate frames and further comprising means for representing one of said two transmitted frames as a still picture over a
- 15 certain period of time followed or preceded by a series of reconstructed intermediate frames providing a moving picture.
7. A method for the representation of video image sequences or scenes with a relative
- 20 movement between a pick-up sensor and the scene transmitted at reduced frame rate substantially as described herein with reference to the accompanying drawings.
8. Apparatus for the reproduction of video
- 25 scenes transmitted at reduced frame rates substantially as described herein with reference to Fig. 4.

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